Numerical Weather Prediction

Near-real time validation of the AATSR meteo product sea surface temperature

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NEAR-REAL TIME VALIDATION OF THE AATSR METEO PRODUCT SEA-SURFACE TEMPERATURE

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Executive summary

A full year of the Advanced-Along Track Scanning Radiometer (AATSR) Meteo product is now available from ESA from 19 August 2002. These data have been downloaded from an ESA FTP server in near-real time as BUFR formatted files. Validation has been performed on these data at the Met Office on a daily basis, with a 2-day lag from data receipt. Meteo product skin Sea Surface Temperatures (SST) have been compared to point measurements of buoy SST; a 1 degree climate SST analysis field compiled from in situ measurements and AVHRR SSTs; plus a 5 degree 5 day averaged in situ data-set. Comparisons of the AATSR Meteo product against TMI SSTs are presented. These validation activities have confirmed the ESA meteo product skin SST to be of a good quality.

From August 2002, only a maximum of 10 orbits of AATSR Meteo product BUFR formatted files were available, which increased to the full 14 orbits per day from November 2002. During the first 6 months of data receipt, it was not unusual for around 2 orbits per day to be unavailable. Data availability has become more reliable from February 2003 onwards.

Comparisons of the AATSR meteo skin SST against buoy SSTs, from 19 August 2002 to 31 July 2003, give a mean (AATSR – buoy) of 0.07K (standard deviation = 0.35K) during night-time, and a mean of 0.03K (standard deviation = 0.46K) during the day. Analyses have shown that there is no cool skin effect observed in the night-time observations as would be expected, implying that the 3-channel Meteo product skin SST may be 0.1-0.2K too warm.

1. INTRODUCTION

The AATSR (Advanced Along Track Scanning Radiometer) instrument upon the Envisat satellite aims to observe Sea Surface Temperature (SST) to within 0.3K accuracy in order to continue the collection of data begun by the ATSR-1 and ATSR-2 instruments upon the ERS 1 and 2 satellites since 1991. Data has been gathered in near-real time at the Met Office from AATSR since 19th August 2002 via the ESA ftp servers. Daily monitoring of these AATSR skin SSTs has been carried out at the Met Office, and further validation against various climate datasets has been performed. A skin to bulk correction is estimated using the Fairall (Fairall et al, 1996) model to account for the difference in SST from the surface skin SST to a depth of around 1m. These bulk SSTs make more suitable measurements when compared against buoy SSTs and other in situ based climate datasets.

Other validation activities involve the production of mean global SST time series, and the comparison of ESA skin SSTs against SSTs observed from the TRMM microwave imager (TMI). Whilst the Met Office gathers and monitors ESA skin SSTs, it also separately calculates the skin SST from brightness temperatures received from ESA using the coefficients supplied by ESA to calculate their own skin SST. These values of skin SST, calculated separately, are compared at the Met Office on a daily basis to ensure consistency of the ESA processing.

Along with the skin to bulk calculations, a diurnal thermocline model is run at the Met Office, based on the Kantha & Clayson model (Kantha & Clayson, 1994) in order to gain knowledge of possible diurnal surface warmings, which are then flagged within the output data. These typically occur more frequently in low-latitudes, and in scenarios of high insolation and low wind-speeds. SSTs influenced by these surface warmings are less characteristic of the overall heat budget of the ocean and so should be excluded or corrected before being assimilated into climate SST datasets. This paper details the validation carried out on AATSR skin SSTs from 19th August 2002 to August 2003, and displays the results. Additional discussions are reported on SST algorithm comparisons, bias's in SSTs, and finally future work and conclusions.

2. DATA AND METHODOLOGY

2.1 AATSR Meteo product

The AATSR Meteo product (ATS_MET_2P, (Envisat products handbook)) is a fast-delivery level 2 product designed for use in meteorological studies, which contains spatially averaged channel brightness temperatures and sea surface temperatures (SSTs) in 10 arc minute cells. The contents of this product are extracted from the 10 arc minute average surface temperature product (ATS_AR_2P) for clear sea views. SST is retrieved using ESA's pre-launch coefficient set, for both the nadir view and for the dual-view combination. In each case, only 11μm and 12μm data are used during the day, and valid 3.7μm data are also included during the night. The product validation described here has used only the dual-view SST both for day and night time.

Meteo product files are written individually, with each encoded in Binary Universal Form for the Representation of data (BUFR). The Meteo product BUFR version does not include a record quality indicator. However, the number of clear pixels in the nadir and dual views, which, in addition to a record quality indicator, has been included in the Meteo product throughout the Envisat validation phase, was added to the BUFR version of the product from 14 February 2003. A full list of the elements of data supplied in the BUFR version of the Meteo product from this date is shown in Table 1.

Table 1. Elements of data supplied in the BUFR version of the AATSR Meteo product

BUFR Descriptor:	Element name:	Units:	To nearest:
001007	Satellite Identifier	Code table	
002019	Satellite Instruments	Code table	
001096	Station Acquisition	Numeric	
025061	Software Identification	Numeric	
005040	Satellite Orbit Number	Numeric	
004001	Year	Year	
004002	Month	Month	
004003	Day	Day	
004004	Hour	Hour	
004005	Minute	Minute	
004006	Second	Second	
005001	Latitude	Degrees	1/6
006001	Longitude	Degrees	1/6
007002	Height or altitude	Metres	1
012180	Averaged 12μm Brightness Temperature for all Clear Pixels in Nadir View	Kelvin	0.01
012181	Averaged 11μm Brightness Temperature for all Clear Pixels in Nadir View	Kelvin	0.01
012182	Averaged 3.7μm Brightness Temperature for all Clear Pixels in Nadir View	Kelvin	0.01
012183	Averaged 12μm Brightness Temperature for all Clear Pixels, Forward View	Kelvin	0.01
012184	Averaged 11μm Brightness Temperature for all Clear Pixels, Forward View	Kelvin	0.01
002185	Averaged 3.7μm Brightness Temperature for all Clear Pixels, Forward View	Kelvin	0.01
002173	Mean Across Track Pixel Number	Numeric	
021086	Number of Pixels in Nadir only, Average	Numeric	
012186	Mean Nadir Sea Surface Temperature	Kelvin	0.01
021087	Number of Pixels in Dual View, Average	Numeric	
012187	Mean Dual View Sea Surface Temperature	Kelvin	0.01
033043	Average Surface Temperature Confidence	Flag table	

2.2 Supply of data from ESA

Envisat makes 14 orbits of the Earth each day, of which up to 10 can be downloaded data directly to the Kiruna receiving station. Meteo product BUFR files for these data have been made available in near-real time (NRT) on the Kiruna FTP site from 19 August 2002. The remaining orbits are generally out of the receiving range of the Kiruna station (these are Kiruna-blind) and their data are not added to the Kiruna FTP site.

The Kiruna-blind orbits have resulted in an absence of night-time observations over most of the Atlantic and part of the east Pacific Ocean (and a corresponding lack of daytime data across parts of the Indian and the west Pacific Oceans). However, the Svalbard receiving station was introduced into the data distribution chain on 7 November 2002, receiving the Kiruna-blind orbits which have been sent in NRT to a second FTP site at ESRIN. The Kiruna-blind orbits prior to the introduction of the ESRIN FTP site, which comprise approximately 5.4% of all orbits in the validation period, have yet to be released by ESA. The remaining orbits whose BUFR Meteo product were readily available and clearly readable comprise approximately 74% of the total number of orbits during the validation period.

A few gaps in the availability have resulted from instrument switch-offs and ground-based technical problems, as detailed in Table 2. Aside from these outages, the data coverage has occasionally been incomplete, with fewer orbits than expected on the servers, resulting in the absence of data from

approximately 10% of the orbits in the period of 19 August 2002 to 31 August 2003 (referred to in this paper as the validation period), although the bulk of these were within the first 6 months. If outages in provision are not backfilled within 4 days, the Met Office experiences a permanent gap in its archive due to on-line storage limitations, and approximately 1.0% of orbits' of Meteo product data are missing from our validation as a result. An additional 1.2% of orbits could not be used due to anomalies in the coding of the BUFR Meteo product received. Figure 1 shows the number of daily global observations of AATSR SST for the period 19 August 2002 to 20 August 2003.

Table 2. AATSR Meteo product availability between 19 August 2002 and 31 August 2003

% of orbits:	Reason for unavailability	Dates
2.0	Technical faults at Kiruna	28 – 30 September 2002, 22 – 24 October 2002 1 – 3, 8 – 9 November 2002
2.2	Switch off for platform manoeuvres	8 – 12 September 2002 17 – 18 December 2002 18 – 21 May 2003
2.0	Switch off for outgassing events	31 January – 3 February 2003 31 July – 4 August 2003
0.6	Switch of for meteor shower	18 – 20 November 2002
1.6	Other instrument switch-offs	25 August 2002 15 – 19 March 2003
10.0	Occasional missing orbits, cause unknown	Various
1.2	BUFR coding errors / poor communication	11 – 12 October 2002 1 January 2003 12 – 14 February 2003
1.0	Late provision of data to FTP sites	19 – 22 March 2003
5.4	Kiruna-blind orbits, before ESRIN FTP site available	19 August – 7 November 2002

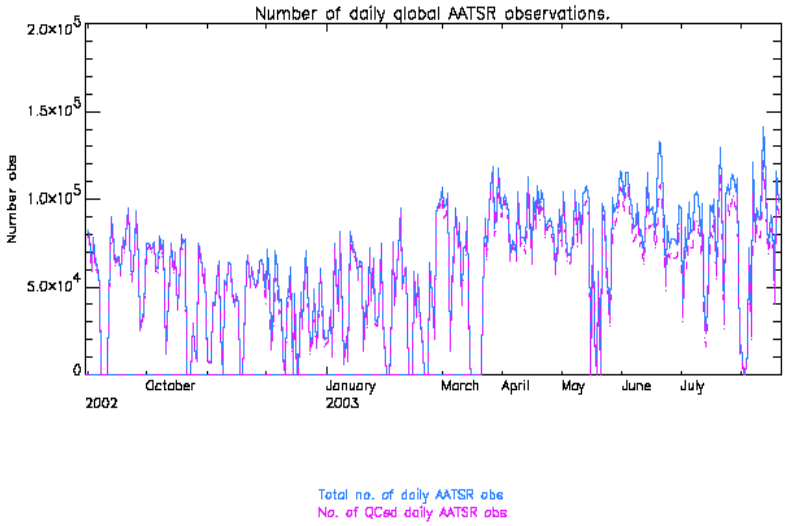


Figure 1 Number of AATSR Meteo product skin SST observations, 1 September 2002 to 31 August 2003

It is our intention to provide a more complete AATSR archive for climate monitoring purposes, for which the release by ESA of all re-processed data, with the exception of that missing due to instrument switch-offs, could increase the coverage to 90% of all orbits in this validation period.

2.3 Buoy data

In this study, AATSR skin SSTs, converted to a bulk SST at around 1m in depth, have been compared to both moored buoys and ships, plus drifting buoy SST measurements. These buoy matchups are extracted on a weekly basis from the Global Telecommunications System, after which the buoy matchup processing at the Met Office (Candy & Horrocks, 2002) is performed and analysed. The buoy matchup dataset is a collection of 79 different fields detailing the buoy observations, AATSR observations and atmospheric and sea surface conditions. The dataset from which these analyses are presented in this paper are from 19 August 2002 to 20th August 2003.

A weekly quality control of individual buoys was performed, in which the mean difference between reported SST and the Met Office NWP background SST field was considered. Buoys which showed a mean weekly bias of more than 1.2K or standard deviation of greater then 0.6K compared to the NWP SST analysis were screened out. Additionally, each single buoy SST report was required to agree within gross limits (8K) with climatology. On the basis of these tests, up to 25% of the buoy reports received each week could be filtered out.

The matching up of the two observation types involves choosing buoy observations which are located within the 10arc-minute resolution grid box of the AATSR observation. The time difference between the two data types must be within ±3 hours. In the event that 2 buoy SSTs are matched up to the same AATSR observation, the buoy observation closest in time to the AATSR observation will be chosen. Efforts to screen out cloudy observations are made by checking the quality control (QC) word calculated during the Met Office processing of the AATSR skin and bulk SSTs. Additionally, careful screening of duplicate matchups, where the same AATSR observation matched with consecutive reports from a single buoy, were performed. The number of matchups per week varied according to gaps in AATSR provision, but could be up to ~ 200.

2.4 MOHSST and HadISST analyses

Two of the climate data sets for global SST provided by the Hadley Centre are used routinely in AATSR validation: the Met Office Historical Sea Surface Temperature (MOHSST) and the Hadley Centre Sea Ice and Sea Surface Temperature dataset (HadISST). MOHSST (Parker et al, 1995) is a gridded data set of sea temperatures at a depth of 1 – 10 metres. Its data are quality controlled in situ observations from ships and buoys, averaged at 5˚ spatial resolution.

A 5-day average version of the MOHSST data set is available in near-real time to provide a gross validation of AATSR every 5 days. The 10 arc minute AATSR SSTs are averaged over the same 5-day periods at 5˚ spatial resolution for their validation against MOHSST.

The HadISST (Rayner et al, 2003) data set is a globally complete 1˚ spatial resolution sea-ice and SST analysis field, produced on a monthly basis. The SST data which contribute to HadISST come from ships, buoys and the Advanced Very High Resolution Radiometer (AVHRR) on the National Oceanic and Atmospheric Administration (NOAA) satellites. The ship and buoy data are averaged into a 1˚ latitude / longitude globally complete field, from which a night-time AVHRR SST field is subtracted. The difference is smoothed to create a field for which the AVHRR data can be corrected. The corrected AVHRR and in situ fields are then averaged together onto a 2˚ latitude / longitude grid which is reconstructed as a 1˚ spatial resolution field, with gaps covered by reduced space optimal interpolation and sea ice fields added to produce the HadISST1 field.

AATSR comparisons have been made against the monthly HadISST1 fields for each calendar month from September 2002 to August 2003 inclusive. The 10 arc minute AATSR SSTs are subtracted from daily climatology SST fields which are at 1˚ spatial resolution. The anomalies are averaged to daily 1˚ spatial resolution and subsequently averaged over the monthly period. A climatological SST normal, averaged over the same period at 1˚ resolution, is added to this, creating a monthly AATSR SST, whose spatial resolution matches the HadISST1 analyses.

2.5 TRMM Microwave Imager (TMI)

The TMI instrument is onboard the Tropical Rainfall Monitoring Mission (TRMM), a joint NASA and NASDA mission, which was launched in November 1997. The TRMM satellite moves from west to east in an inclined orbit providing data at various local times between latitudes 40ºS and 40ºN. The TMI is a conical scan microwave radiometer with channels at five separate frequencies: 10.7, 19.4, 21.3, 37 and 85.5GHz and a spatial resolution of about 50km. The 10.7GHz channel is used to retrieve SST as it is insensitive to water vapour and cloud. This gives an advantage over infrared sensors as cloudy (although non-precipitating) coverage can be viewed with TMI. In addition to precipitation, the TMI does have sensitivities to sea surface roughness and so the microwave SST retrieval attempts to account for these effects. Details of the physical retrieval algorithm, which aims to derive SST to an accuracy better than 0.5K, are given in Wentz & Meissner, 2000. Figure 2 shows the monthly averaged TMI SST for July 2003. This study includes comparisons of AATSR SSTs against TMI SSTs. The TMI SSTs have been retrieved as daily averaged files from the Remote Systems Website http://www.ssmi.com between –40 and 40 degrees latitude.

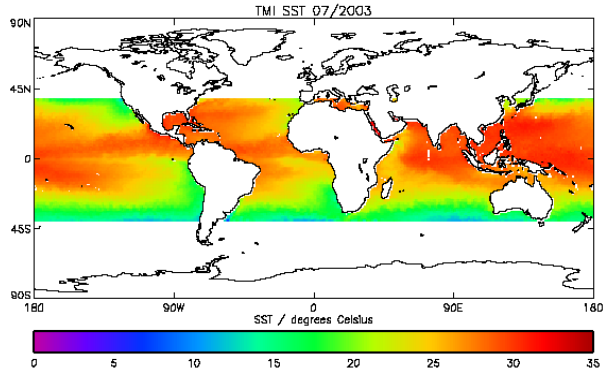


Figure 2 Monthly averaged SST from the TRMM Microwave Imager

2.6 Met Office processing of skin to bulk SST differences

The Met Office receives the Meteo product containing skin SST, brightness temperatures and other related information in near-real time. On a daily basis, the skin SSTs at the Met Office are retrieved from BTs using ESA launch coefficients and compared to the ESA skin SST, which are retrieved using the same coefficients, and comparisons made to check for errors.

These Met Office derived skin SSTs are then processed to a bulk SST, which is the temperature of the ocean at around 1 metre in depth. This is done by using the Fairall model (Fairall et al, 1996) and is necessary because the satellite observes a radiative skin temperature which is always cooler than the sub-skin by more than 0.1K. For obtaining SST for climate purposes we require the bulk temperature which provides a more comparable measurement when looking at other climate datasets, and is more representative of the overall heat capacity of the ocean.

At night the sub-skin SST is representative of the bulk SST at around ~ 1m in depth. However, during the day the sub-skin SST can become warmer than the bulk SST by several Kelvins, especially in cases of strong insolation & low wind speed where thermal stratification results. These locations are typically in low-latitudes, but can reach mid-latitudes if local atmospheric conditions are favourable. These diurnal warming effects are modelled at the Met Office, using the Kantha-Clayson model to try to predict ocurrances of warmings within the 10 arc minute resolution cells, with NWP fluxes and wind observations needed for inclusion in the models. Such predictions are flagged in the observation record and affected observations are not included in further analyses. A diagram showing the processing scheme at the Met Office and the how data is received from ESA is shown in figure 3.

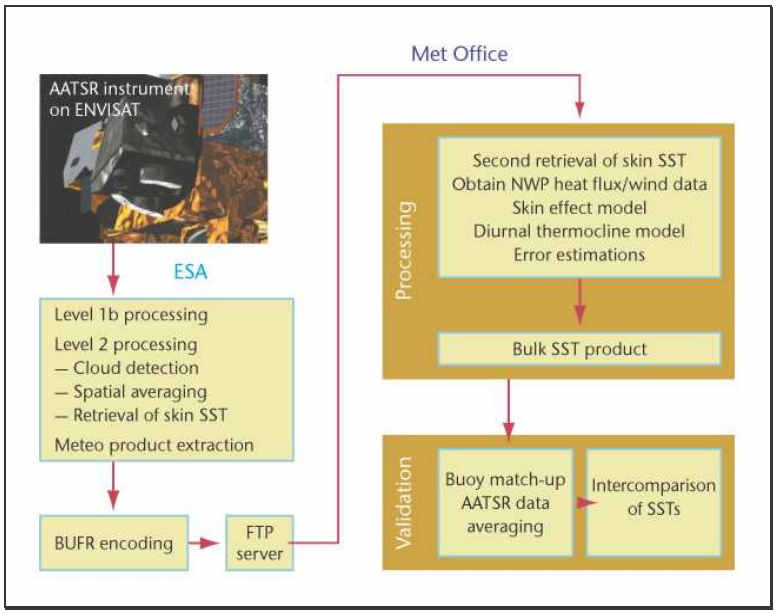


Figure 3 Meteo product data chain and the processing carried out at the Met Office.

The validation datasets used are measures of the bulk SST, and so comparisons of bulk AATSR SST against our validation datasets have been made to complement the skin SST analyses.

2.7 Error estimation

An error estimation field is evaluated within the Met Office processing of the AATSR Meteo product as an attempt to assess the possible error of the bulk SST retrieval according to whether the recommended retrieval is a 2-channel or 3-channel retrieval. It is intended as information to allow AATSR data to be assimilated into the HadISST1 analyses of the Hadley Centre. The method uses a variety of factors and is not intended to be static, but to evolve.

The error estimate for each observation is calculated as a possible error in degrees K, and has contributions as listed in Table 3. The final error (in degK) is computed as the square root of the sum of the squares of all the components of individual errors, in (1):-

$$\text{Final error} = \sqrt{(\sum \text{error components}^2)} \qquad (1)$$

or, in more detail, in (2):-

$$\begin{aligned}\text{Final error} = \sqrt{(}&\text{Npixels_error}^2 \; + \\ &\text{ice_error}^2 \; + \\ &\text{model_error}^2 \; + \\ &\text{bulk_error}^2) \end{aligned} \qquad (2)$$

where *Npixels_error, ice_error, model_error* and *bulk_error* are calculated from the tests listed in Table 3.

Table 3. List of contributions to final error estimation value.

Tests to calculate error components	Error component
The number of pixels making up each 10 arc minute cell.	Npixels_error
Error contribution from SST algorithm.	Model_error
Error contribution due to type of skin model used.	Bulk_error
Do we consider that sea-ice exists within the observation cell?	Ice_error

3. METEO PRODUCT RESULTS

3.1 Dual view SSTs

Global plots of daily and monthly seas surface temperature from the Meteo product have been produced throughout the validation period. As an example, the dual view skin SST for 3 June 2003 is shown in Figure 4. On this day, all 14 orbits of the satellite yielded SST data which was delivered in the Meteo product to the FTP sites.

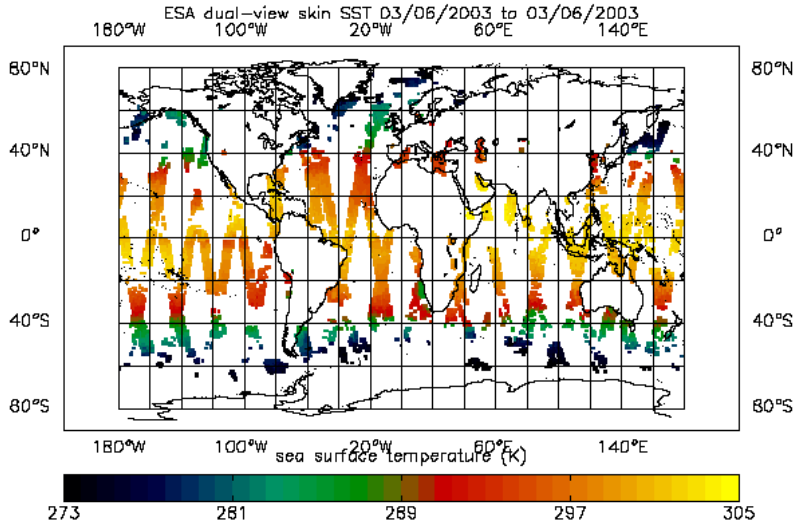
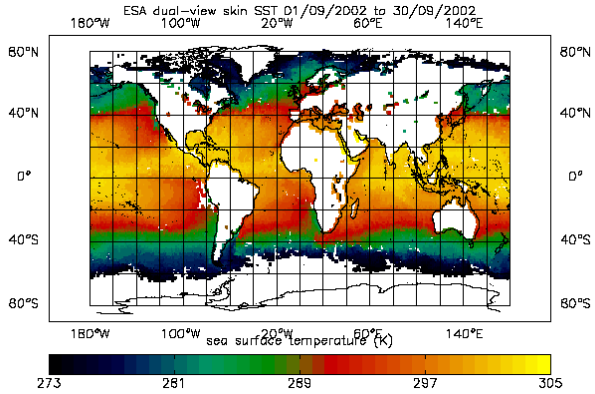
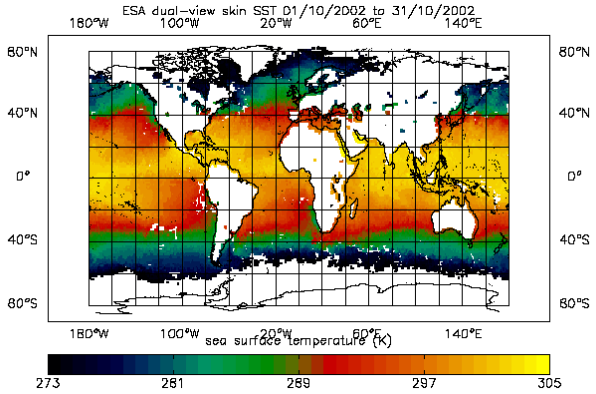
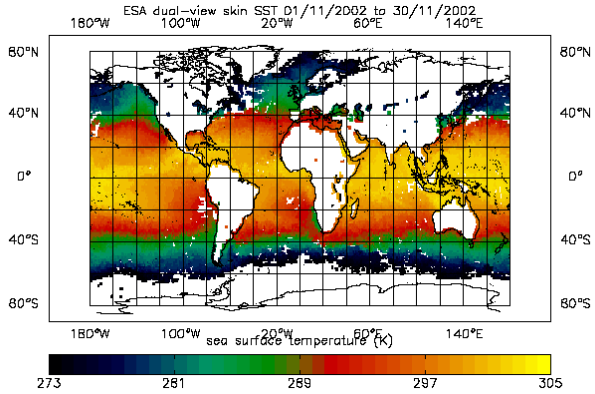


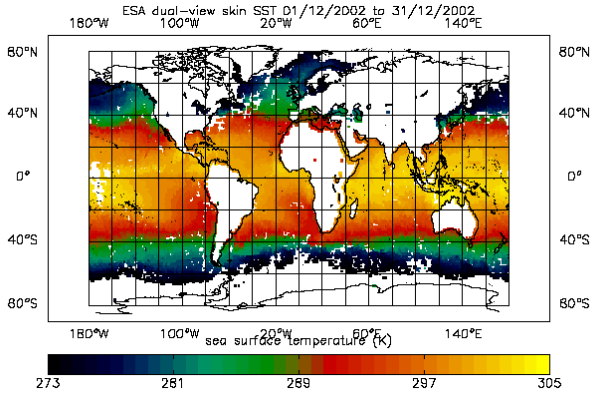
Figure 4 Dual view skin SSTs from the Meteo product of 3 June 2003

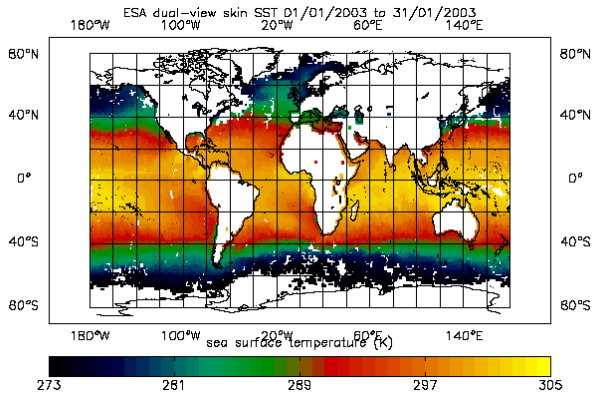
The monthly mean SSTs have been plotted globally for each of the 12 calendar months, September 2002 to August 2003 inclusive, in Figure 5. One clear feature is the cool SST in the south-east Atlantic to the west of South Africa, and in the north-east Pacific near the west coast of USA, as is expected due to the cold Benguela and California currents respectively in the oceanic gyres. The seasonal variations in SST can be seen in both hemispheres and the gaps in monthly mean SSTs suggest areas of persistent cloud cover, such as that in the south-east Pacific near the coast of Peru.

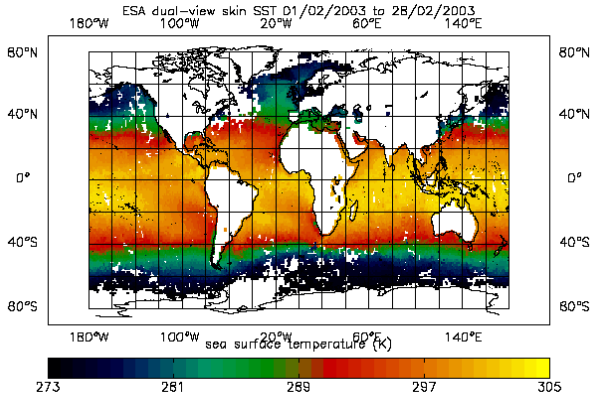

ESA dual-view skin SST 01/09/2002 to 30/09/2002
180°W 100°W 20°W 60°E 140°E
80°N 40°N 0° 40°S 80°S
sea surface temperature (K)
273 281 289 297 305

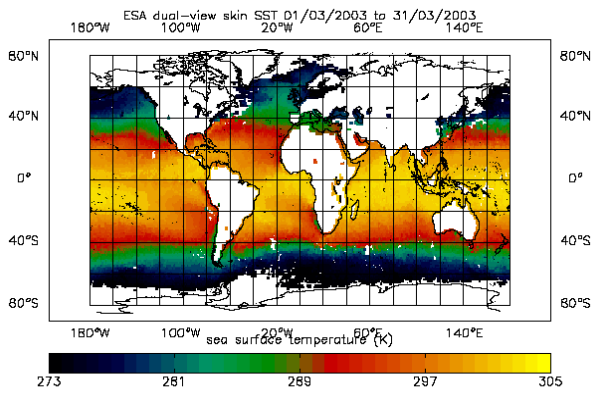

ESA dual-view skin SST 01/10/2002 to 31/10/2002
180°W 100°W 20°W 60°E 140°E
80°N 40°N 0° 40°S 80°S
sea surface temperature (K)
273 281 289 297 305

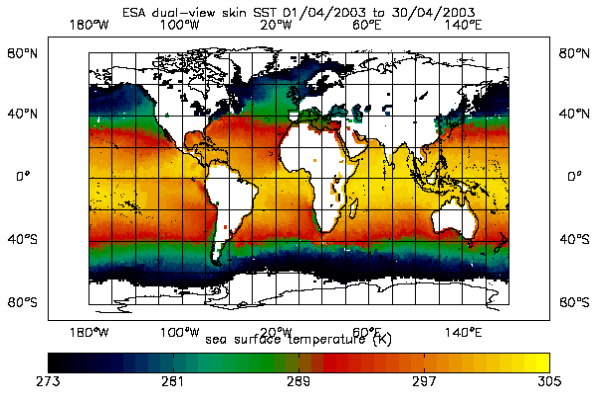

ESA dual-view skin SST 01/11/2002 to 30/11/2002
180°W 100°W 20°W 60°E 140°E
80°N 40°N 0° 40°S 80°S
sea surface temperature (K)
273 281 289 297 305


ESA dual-view skin SST 01/12/2002 to 31/12/2002
180°W 100°W 20°W 60°E 140°E
80°N 40°N 0° 40°S 80°S
sea surface temperature (K)
273 281 289 297 305


ESA dual-view skin SST 01/01/2003 to 31/01/2003
180°W 100°W 20°W 60°E 140°E
80°N 40°N 0° 40°S 80°S
sea surface temperature (K)
273 281 289 297 305


ESA dual-view skin SST 01/02/2003 to 28/02/2003
180°W 100°W 20°W 60°E 140°E
80°N 40°N 0° 40°S 80°S
sea surface temperature (K)
273 281 289 297 305


ESA dual-view skin SST 01/03/2003 to 31/03/2003
180°W 100°W 20°W 60°E 140°E
80°N 40°N 0° 40°S 80°S
sea surface temperature (K)
273 281 289 297 305


ESA dual-view skin SST 01/04/2003 to 30/04/2003
180°W 100°W 20°W 60°E 140°E
80°N 40°N 0° 40°S 80°S
sea surface temperature (K)
273 281 289 297 305

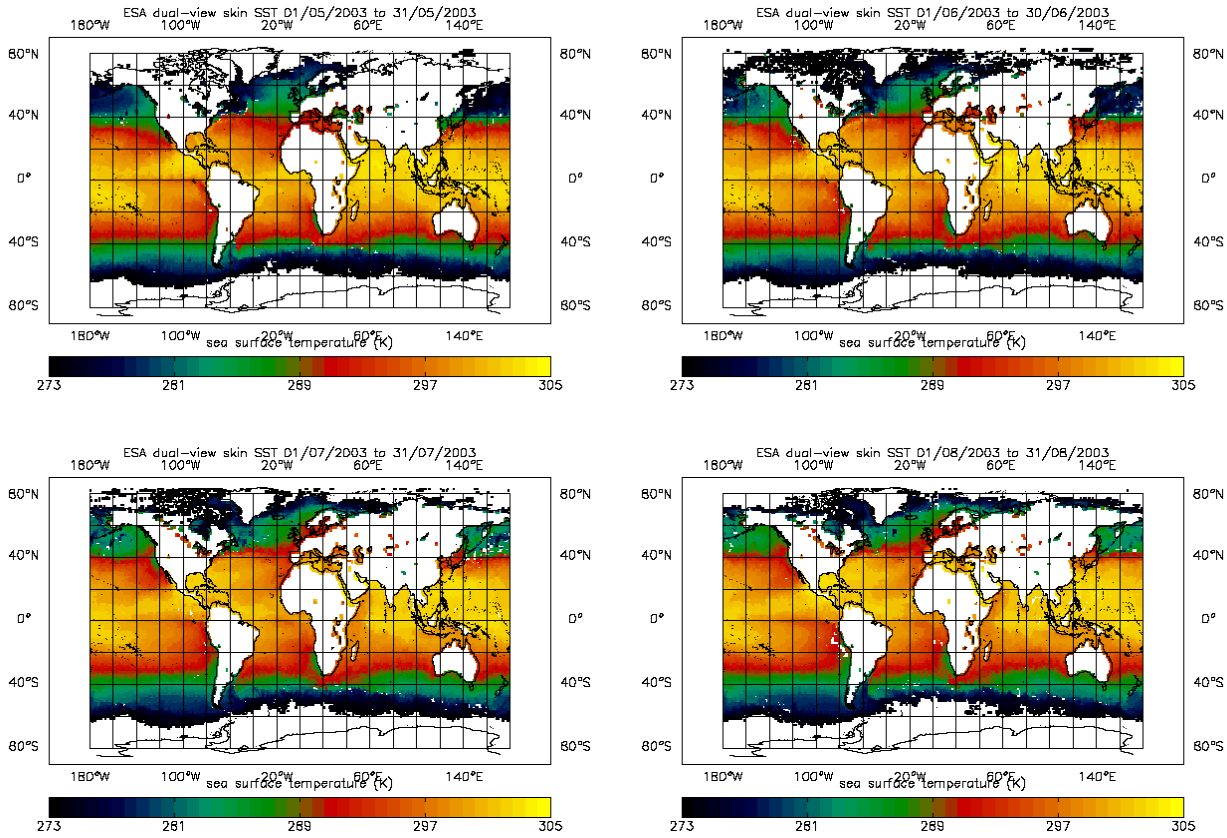


Figure 5 Monthly mean dual view skin SST global plots, from the Meteo product of September 2002 to August 2003

3.2 SST Algorithm Comparison

Different retrieval coefficients are used to calculate the dual-view 2-channel skin SSTs (hereafter D2) day or night & dual-view 3-channel skin SSTs (hereafter D3) only at night. A bias between these 2 retrievals has been observed to exist, showing that the night-time skin SSTs are not cooler than day-time skin SSTs, as would normally be expected due to diurnal warming, implying that D3 may be too warm.

From the period September 2002 to August 2003, results of mean differences show that D2 are cooler than D3 by ~0.14K (σ=0.2K, n=9511981), where all skin SSTs calculated at the Met Office (using ESA pre-launch coefficients) which pass a data confidence word are used.

Comparisons of the dual-view skin SSTs against the HadISST1 climate dataset show that the D3 values are similar to HadISST, whilst the D2 are warmer (see Table 4). These subset of statistics are taken where good skin to bulk calculations are performed on the skin SSTs for September 2002 – August 2003. This is a smaller subset of data to that used to calculate the D2 minus D3 differences in the previous paragraph, and produces slightly different differences between the two analyses of D2 and D3 differences of 0.02K.

Table 4. Results of Met Office dual-view skin SST minus HadISST1.

Retrieval type	Mean (skin SST – HadISST1), K	Standard deviation, K	Number in sample
3-channel	0.02	0.58	242224
2-channel	0.14	0.61	242383

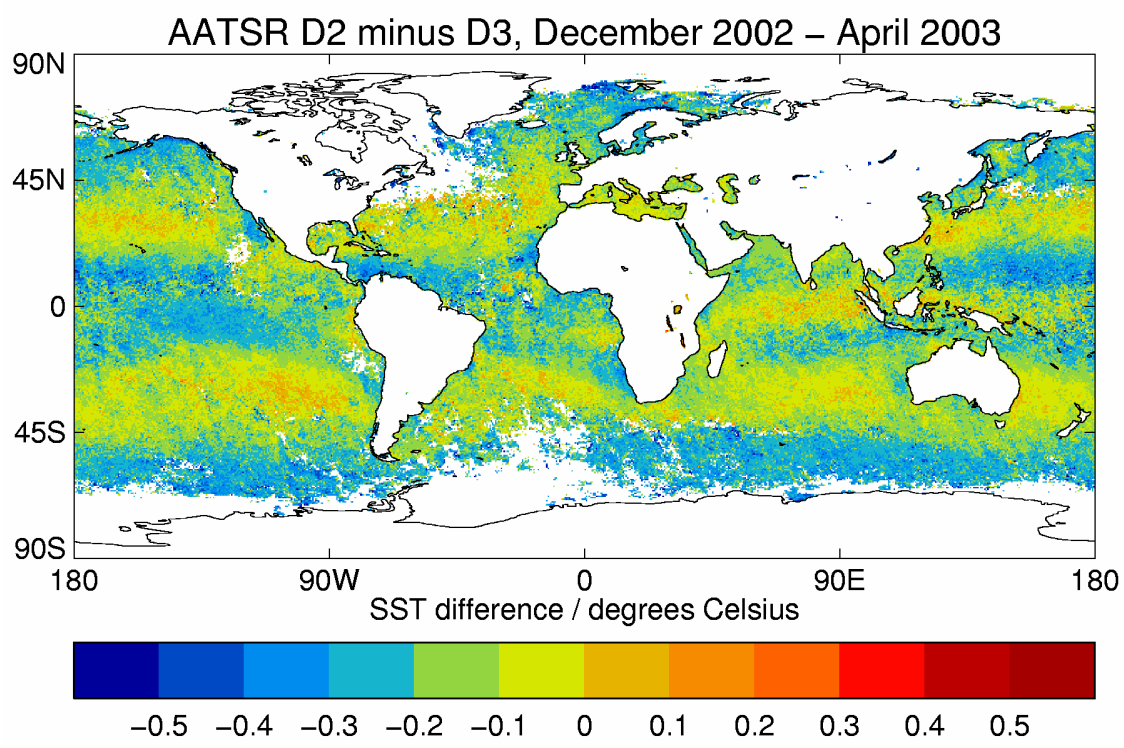


Figure 6 Global map of mean D2-D3 skin SSTs.

Figure 6 shows the latitudinal and longitudinal variation of the differences which lead to a day-night bias in the retrievals.

3.3 Biases in Sea Surface Temperature retrievals

Biases in SST retrievals are caused by two factors. Firstly, retrieval errors are a contributor. These are state dependent. The retrieval errors vary with atmospheric state, as a different atmosphere was used by the radiative transfer model (RTM) used to calculate the retrieval coefficients, than the state at the time of satellite measurement. This leads to the retrieval errors varying with latitude, longitude and season. An example of the variation with latitude is shown in figure 7.

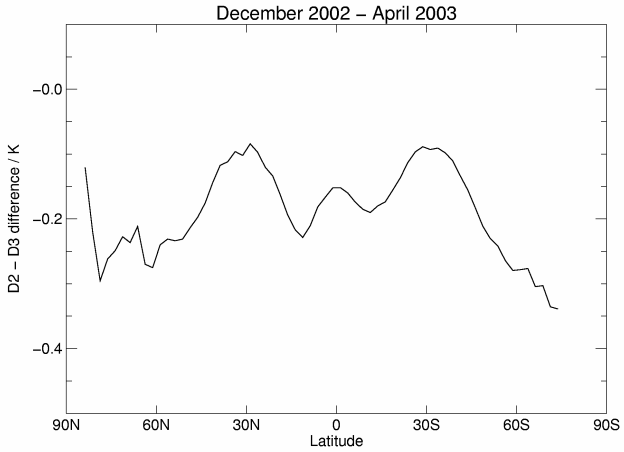


Figure 7 Variation of D2 minus D3 retrievals with latitude for an AATSR sample from December 2002 to April 2003

Secondly, there is a mean global offset between D2 and D3 retrievals due to errors in the Radiative Transfer Models (RTMs) used to calculate the retrieval coefficients. To estimate this offset, comparisons are made against night-only insitu measurements which have been "adjusted" to a skin SST measurement. For an AATSR sample from December 2002 to April 2003, D2 is 0.03K too warm and D3 is 0.19K too warm with regard to insitu skin observations.

4. VALIDATION RESULTS

4.1 Comparisons with buoy SSTs

Figure 8 shows the coverage of buoy SSTs matched up with AATSR observations from 19 August 2002 to 20 August 2003. They were matched up when the buoy SST measurement was coincident in a 10 arc minute AATSR observation cell, and where the two measurements were taken within 3 hours of each other. A good spread of matchups has been obtained for the period, but with fewer in the Southern Oceans, as expected. Table 5 shows statistics (using 3 sigma standard deviation test to eliminate outliers) from these analyses of buoy SSTs matched up with AATSR skin and bulk SSTs during this same period. The results display how a cool skin with respect to buoy SSTs are not observed at night, which leads to the conclusion that the night-time (3-channel) SST retrievals are too warm. The AATSR bulk SSTs are around 0.2K warmer than the buoy SSTs.

Figure 9 shows the time series for the year for skin and bulk SSTs against buoy SSTs. The results show that the AATSR SSTs are mainly within the ±0.3K accuracy required for AATSR, but the skin SSTs are closer to the buoy SSTs than the bulk SSTs.

Table 5. Statistics of co-located AATSR minus buoy SSTs for 19 August 2002 to 20 August 2003

SST type	Subset	Mean (AATSR – buoy SST), K	Standard deviation, K	Number matchups
ESA Skin	Day + night	0.05	0.41	6691
ESA Skin	Day	0.03	0.46	3611
ESA Skin	Night	0.07	0.35	3080
Bulk	Day + night	0.21	0.40	5646
Bulk	Day	0.19	0.35	3028
Bulk	Night	0.23	0.34	2621

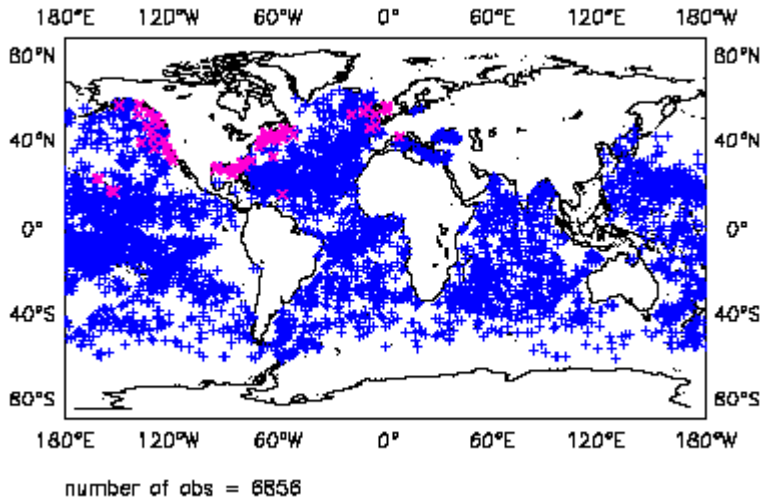


Figure 8. Locations of buoy SSTs matched with AATSR SSTs from 19 August 2002 to 20 August 2003.

(pink = moored buoys, blue=drifting buoys)

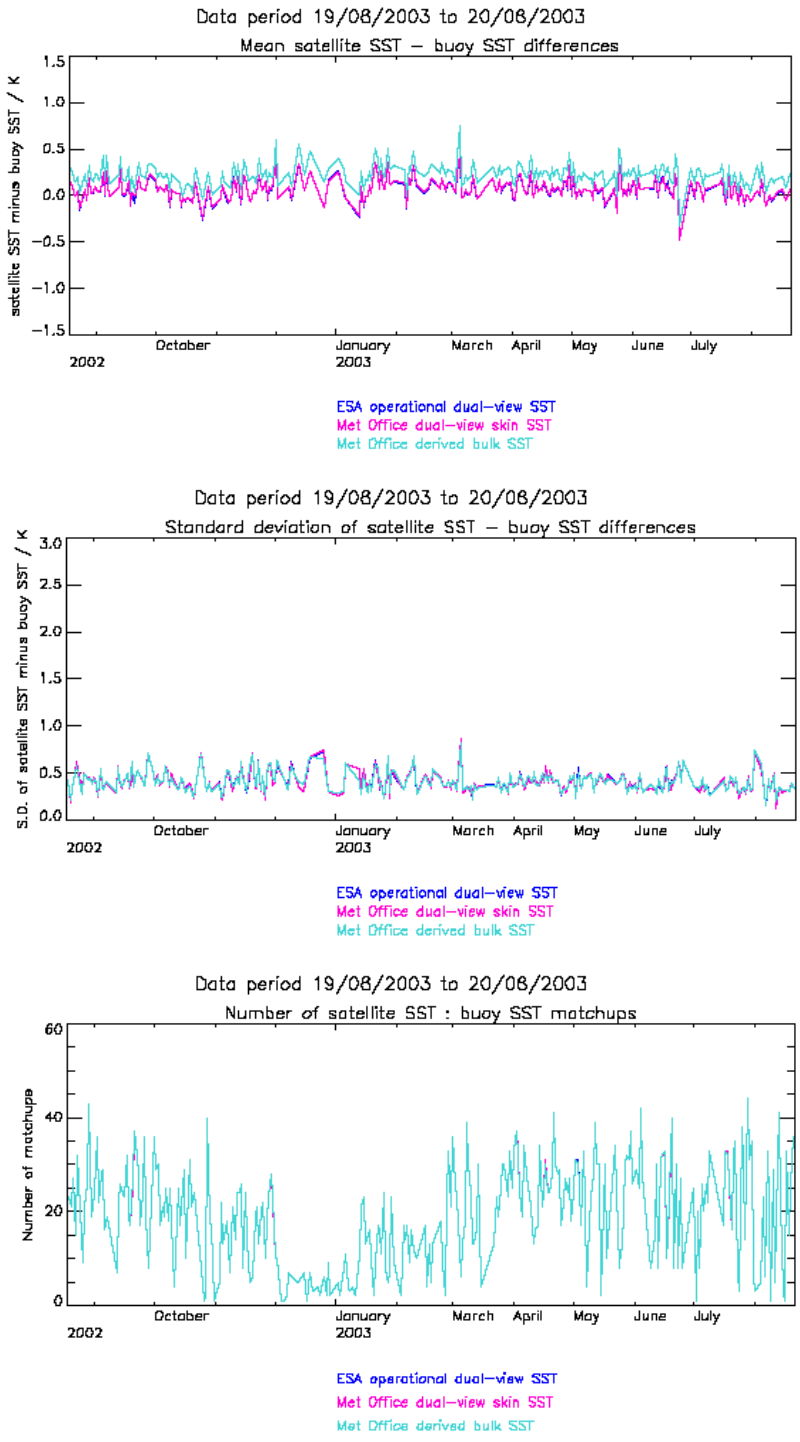


Figure 9. Time series of bulk and skin SST minus buoy SST, standard deviation, and number of matchups

On 25 June 2003, a trough can be observed for the Met Office skin and bulk SSTs. The daily mean Met Office skin SST minus buoy SST is –0.49K. This anomaly is contributed to by three matchups on the same day (out of only 8 matchups which include Met Office skin SST), around 21:50 in the evening, all in the

same local area of the Bay of Biscay. Differences are not too large limited to a maximum of around 1.6K. The indications are that the AATSR observations could be affected by cloud contaminated pixels making up the 10 arc minute cell. Table 6 displays the three matchups out of a total of 32 for this day which contribute to the anomaly. The AATSR ESA skin SST minus buoy SST is –0.09K for this day. The ESA skin SST is comparable to the Met Office skin SST for the day, however a larger sample of matchups is available for the ESA skin SSTs which reduces the anomaly. Fewer Met Office skin SSTs are available due to the unavailability of Numerical Weather Prediction model fields at this time.

Table 6. Anomalous AATSR/buoy matchups in the Bay of Biscay, 25 June 2003

Buoy SST, K	Met Office skin SST, K	Latitude, degrees	Longitude, degrees
292.6	291.9	46.7	-4.5
290.5	289.4	51.0	-7.8
290.6	288.9	48.3	-5.7

From AATSR/buoy matchups compiled from 19 August 2002 to 20 August 2003, only 8 daily mean values of ESA skin SST minus buoy SST are greater than or less than 0.3K. Thus, most of the years results indicate that the AATSR retrievals are within the boundaries required for AATSR SST data ignoring the skin effect.

Regional samples of from the buoy matchup files have also been analysed in order to look for characteristics in the main ocean basins. Table 7a displays the statistics for the analysed regions, and Table 7b describes the latitude/longitude boundaries of the regions chosen for a matchup period of 19 August 2002 to 20 August 2003.

Table 7a. Statistics for AATSR SSTs compared to buoy SSTs for difference oceanic regions, between 19 August 2002 and 20 August 2003

		AATSR ESA skin SST – buoy SST			AATSR bulk SST – buoy SST		
Region	Sample	Mean difference, K	Standard deviation, K	Number matchups	Mean difference, K	Standard deviation, K	Number matchups
Tropical Atlantic	Night	0.16	0.29	108	0.33	0.25	95
	Day	0.12	0.34	205	0.25	0.35	170
	Night/day	0.14	0.33	314	0.28	0.34	268
Indian Ocean	Night	0.10	0.29	31	0.26	0.27	26
	Day	0.08	0.35	17	0.24	0.38	15
	Night/day	0.09	0.31	48	0.25	0.31	41
North Atlantic	Night	0.03	0.40	55	0.17	0.33	47
	Day	0.06	0.51	87	0.22	0.49	70
	Night/day	0.05	0.47	142	0.19	0.40	116
Southern Ocean	Night	0.02	0.38	237	0.12	0.37	185
	Day	-0.13	0.41	223	-0.04	0.41	173
	Night/day	-0.05	0.40	459	0.05	0.39	358
Tropical W Pacific	Night	0.01	0.28	77	0.21	0.26	65
	Day	-0.02	0.43	36	0.20	0.47	31
	Night/day	0.01	0.34	114	0.22	0.31	95

Table 7b. Latitude and longitude boundaries for oceanic areas used in regional analyses.

Region	Latitude range (degrees)	Longitude range (degrees)
Tropical Atlantic	-20 to 20	-40 to 0
Indian Ocean	-20 to 0	60 to 80
North Atlantic	40 to 60	-40 to –15
Southern Ocean	-90 to -40	-180 to 180
West Pacific	-10 to 10	140 to 180

The results show that the AATSR skin SSTs in the North Atlantic, Southern Ocean and West Pacific are similar to the matched up buoy SSTs during night-time. The corresponding AATSR bulk SSTs have a slightly higher mean difference with buoy SSTs ranging from 0.12K to 0.33 K for these regions at night-time. The buoy SSTs have a better agreement with the AATSR skin SSTs, than the bulk SSTs.

Results during night-time for the Tropical Atlantic and Indian Ocean regions show that the mean difference indicates that AATSR skin SSTs are warmer than the buoy SSTs by 0.16 and 0.1K respectively. These differences are slightly larger than for the other regions and for the overall global means. The statistics are only calculated on matchups where a diurnal thermocline is thought not to exist, and being night-time this is unlikely. The results do not indicate the possibility of aerosols affecting the results.

During the day, the mean (AATSR skin SST – buoy SST) for the Southern Ocean is –0.13K (standard deviation = 0.41K), so here the buoy SSTs are slightly warmer than the AATSR SSTs. Slight cloud contamination may contribute to this.

4.2 Comparisons against MOHSST and HadISST

AATSR skin SSTs have been converted to estimated bulk SSTs using the processing scheme described in Section 2.6. For comparisons against MOHSST, the skin and bulk SSTs have been averaged over 5-day periods (pentads) at 5° resolution and the corresponding MOHSST data sets have been subtracted from them. The global mean skin and bulk SST – MOHSST differences with standard deviation are plotted for each pentad of 19 August 2002 – 18 August 2003 in Figure 10. No Meteo product was available during the pentad of 17-21 March 2003, and the mean differences for skin and bulk – MOHSST of -0.66 K and -0.48 K respectively on 17-21 December 2002 were calculated using only 96 means at 5° resolution, due to the low availability of AATSR data in this period. For the other 50 pentads, between 100 and 1000 grid cells at 5° were used to produce the global means, all of which lay within the ±0.3 K range for both skin and bulk SST comparisons against MOHSST. The high standard deviations can partly be attributed to the coarse resolution, as the largest differences tended to be found in regions of strong SST gradients such as the Gulf Stream, or regions where small numbers of in situ data contributed to MOHSST, such as the Southern Oceans. The fall in standard deviations during November 2002 coincided with the introduction of Kiruna-blind orbits into the data distribution chain, perhaps the existence of more global coverage with the Kiruna-blind orbits led to this characteristic.

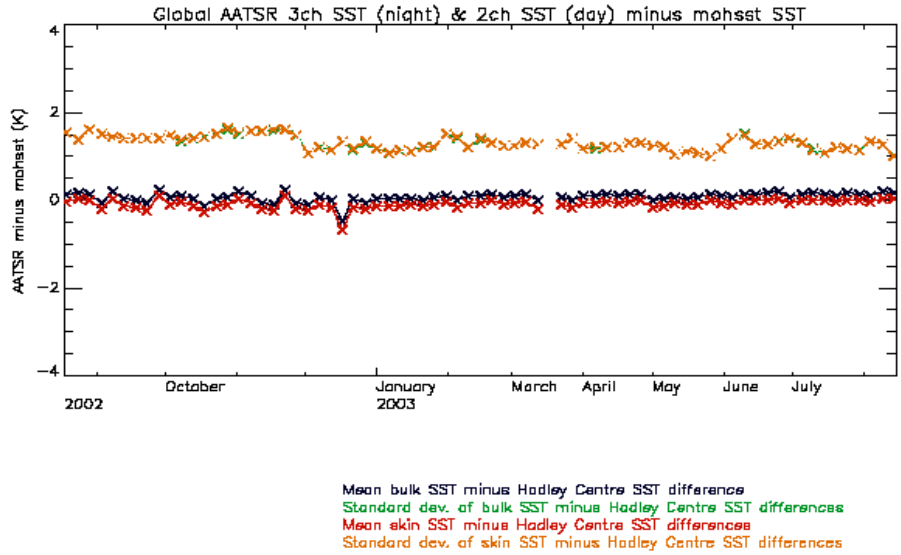


Figure 10 Global AATSR skin and bulk SST – MOHSST comparisons, 19 August 2002 – 18 August 2003

For comparisons against HadISST, the skin and bulk SSTs have been averaged monthly at 1° resolution and the monthly HadISST1 fields have been subtracted from them, using the method described in Section 2.4. Global plots of the monthly SST differences have been produced for each calendar month of the validation period, with the August 2003 skin SST minus HadISST1 plot in Figure 11. This demonstrates that the SST differences are generally within ±1 K away from the poles, although many regions such as across the south Atlantic and north-west Pacific, where much of the AATSR data is significantly warmer or cooler than HadISST1, tend also to be regions where cloud detection has frequently resulted in the unavailability of AATSR SSTs. This suggests that cloud contamination may have affected the AATSR data in these regions.

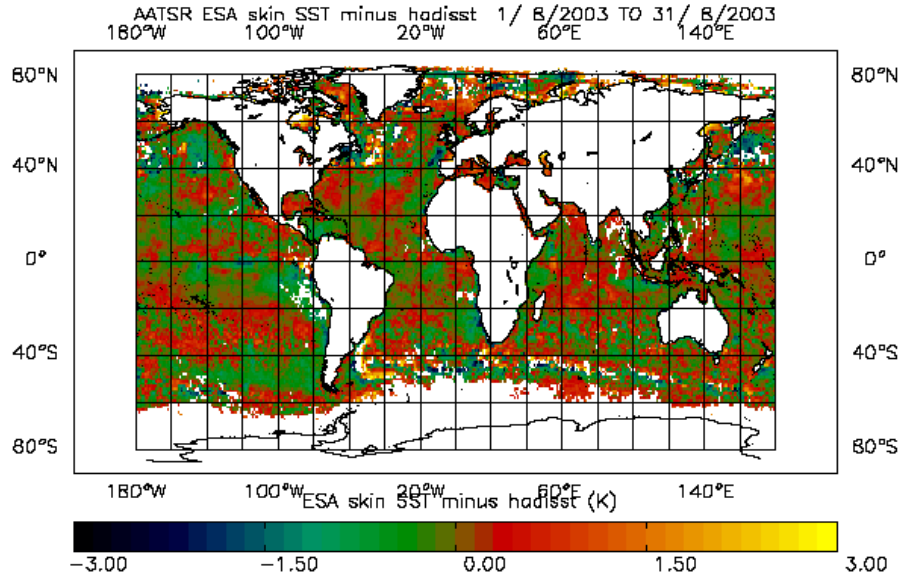


Figure 11 Global plot of AATSR skin SST minus HadISST1, August 2003

Monthly and annual global differences between AATSR ESA skin or bulk SSTs and HadISST1 at 1° resolution and standard deviations are listed in Table 8. Results are presented for the ESA skin SST, whilst the bulk SST is derived from the Met Office derived skin SST. Statistics for bulk SST are only presented where a 'good'

skin-bulk temperature difference has been calculated which is why a lower sample of bulk SSTs are included. Factors such as whether NWP model fields are available for a particular observation affect the calculation of the modelled skin minus bulk difference. The annual comparison takes a mean and standard deviation for all 1° spatial resolution comparisons in over each of the 12 months. The mean differences between AATSR skin SST and HadISST1 are generally closer to zero than the mean differences between AATSR bulk SST and HadISST1, although these results make no correction for the interalgorithm bias. The increase of standard deviation to 1.02K, for the ESA skin SST results for July 2003, coincides with a period where we observed anomalously cooler skin SSTs by about 1K in the global results when compared to bulk SST, possibly due to sampling errors.

Table 8. Monthly and annual comparisons of AATSR SST minus HadISST1 (derived using a 3 sigma standard deviation test to identify outliers.

	AATSR ESA skin SST – HadISST1:			**AATSR bulk SST – HadISST1:**		
Period:	**Mean, K:**	**Standard deviation, K:**	**Number of 1° comparisons :**	**Mean, K:**	**Standard deviation, K:**	**Number of 1° comparisons :**
September 2002	-0.06	0.70	32288	0.09	0.60	31377
October 2002	-0.09	0.62	31663	0.06	0.60	30465
November 2002	-0.07	0.61	30280	0.08	0.60	29132
December 2002	-0.12	0.64	28866	0.02	0.67	12594
January 2003	-0.09	0.60	31545	0.09	0.62	27881
February 2003	-0.04	0.62	30644	0.11	0.61	28970
March 2003	-0.03	0.59	33353	0.12	0.59	32183
April 2003	-0.02	0.57	34012	0.14	0.57	32851
May 2003	-0.04	0.60	33420	0.12	0.60	32057
June 2003	-0.01	0.68	34114	0.15	0.67	30963
July 2003	0.03	1.02	34321	0.14	0.69	31798
August 2003	0.01	0.69	33697	0.15	0.64	31540
Annual: September 2002 – August 2003	**-0.04**	**0.66**	**388223**	**0.11**	**0.62**	**351811**

4.3 Impact of AATSR in HadISST

Section 4.2 concerns the HadISST1 product in which in situ SST data is used to correct a 1° gridded night-time AVHRR SST field. However, studies to produce a parallel version of the HadISST1 product using AATSR SST data in place of AVHRR have been made. Comparisons between the preliminary HadISST products for September 2003, constructed in the same way as described for the HadISST1 product in Section 2.4 (see also Rayner et al, 2003) before the corrections are made for the ice fields, have produced the plots in Figure 12. Here, the corrected AATSR field has been subtracted from the corrected AVHRR field, to a mean global difference of 0.01 K, standard deviation 0.12 K.

Larger differences between the two products can be detected clearly on regional scales. The east Atlantic, particularly near Africa, appears as an area where the HadISST product using AVHRR is cooler than that using AATSR. Comparison of the September HadISST product using AVHRR with and without the in situ SST correction, and the same comparison using AATSR data confirm that AVHRR requires a greater correction in the east Atlantic region than AATSR. The initial AVHRR data is more than 0.3 K greater than the corrected AVHRR data through much of this region, while the initial AATSR is generally within ±0.1 K of the corrected AATSR here. This provides evidence that the aerosol correction in AATSR SST data gives it an advantage over AVHRR.

The greatest differences between initial and corrected AATSR data are seen in the Southern hemisphere around 40º S, where the initial AATSR is around 0.4 K warmer than the corrected product in the south-west Indian Ocean, and around 0.3 K cooler than the corrected product in the south-west Pacific Ocean. However, these regions also require large corrections to their AVHRR SST data. Globally, the mean corrected AATSR data is 0.04 K cooler than its initial data, while the mean corrected AVHRR data is 0.03 K warmer than its initial data, but these differences have a standard deviation of 0.13 K for AATSR compared to 0.16 K for AVHRR, suggesting that AATSR SSTs are slightly more consistent than AVHRR SSTs in their comparison against in situ data.

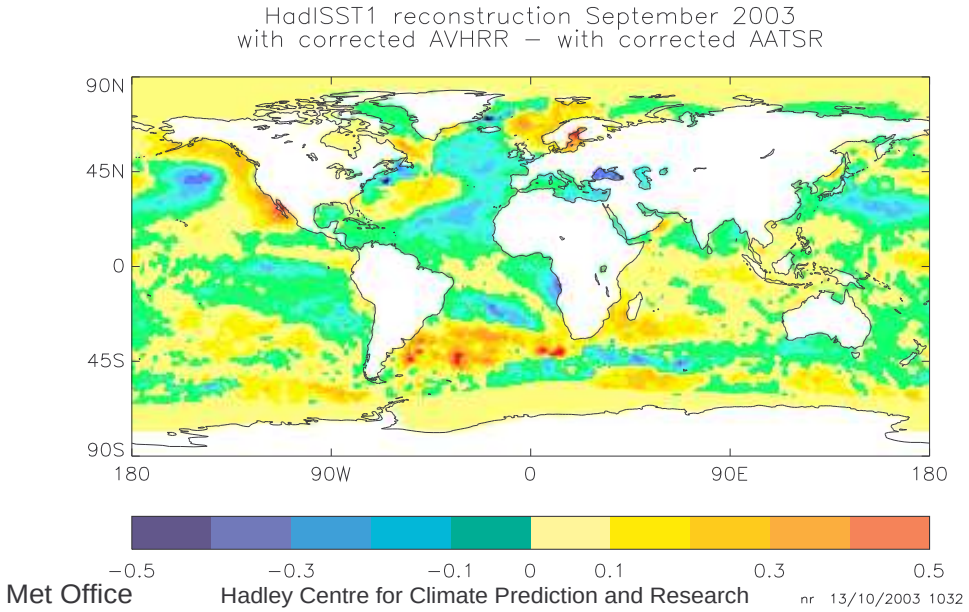


Figure 12. Global differences between HadISST analyses using AVHRR and AATSR SST fields, September 2003

4.4 Comparisons of AATSR against TMI

Comparisons of AATSR against TMI data have been made for June, July and August 2003. Table 9 displays the differences statistics, and Figure 13 shows an AATSR skin 2 & 3-channel SST – TMI for July 2003. Only night-time AATSR data are included to avoid diurnal thermocline effects.

Table 9. Statistics of AATSR – TMI for June, July, August 2003: NIGHT ONLY

	AATSR Skin 2-channel SST – TMI			AATSR Skin 3-channel SST - TMI		
Month	**Mean, K**	**St.Dev, K**	**Number**	**Mean, K**	**St.Dev, K**	**Number**
June 2003	-0.27	0.59	18245	-0.14	0.59	18252
July 2003	-0.3	0.58	17717	-0.15	0.56	17731
August 2003	-0.37	0.58	17352	-0.23	0.58	17352

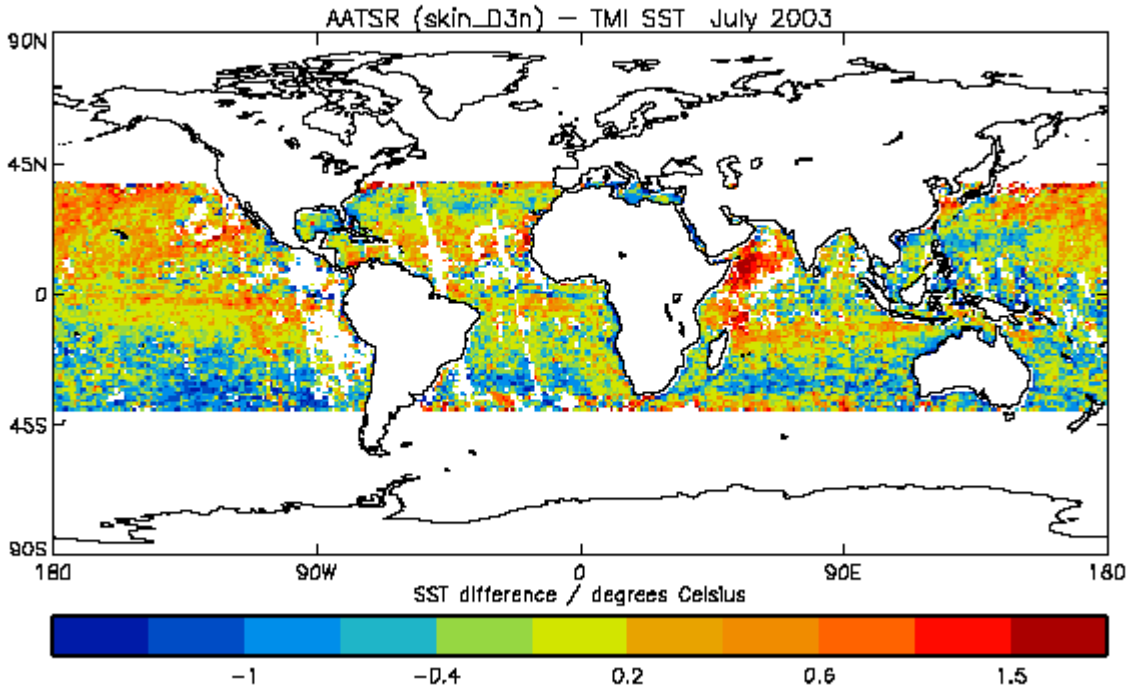


Figure 13. Global map of mean AATSR channel-3 skin SST – TMI SST for July 2003

Overall, the results indicate that the AATSR skin 2-channel SST is ~ 0.3K cooler than TMI, and the AATSR skin 3-channel SST is ~ 0.2K cooler than TMI. However, there is a large regional variation in the differences, with SSTs warmer than TMI in the Northern Hemisphere and cooler than TMI in the Southern Hemisphere. The large negative differences south of 20 degrees South may be influenced by some residual cloud contamination in the AATSR data. Note that similar comparisons using ATSR-2 SSTs have given similar hemispheric patterns, as reported in Saunders et al; 2004.

5. CONCLUSIONS AND FUTURE WORK

Comparison of the AATSR Meteo product against various SST datasets over a full year (August 2002 to August 2003) has confirmed that the AATSR instrument is performing satisfactorily. Comparisons against in situ buoy SSTs and the MOHSST and HadISST fields have confirmed that the AATSR skin and bulk SSTs are performing to the required 0.3K accuracy. However, the skin SSTs are too warm being closer to the buoy AATSR SSTs than the bulk SSTs, with the mean night-time AATSR skin SST – buoy SST at 0.05K and the mean night-time AATSR bulk SST – buoy SST at 0.23K. The same feature has been seen with HadISST1, as the mean AATSR skin SST – HadISST1 is -0.04K, compared to the mean AATSR bulk SST – HadISST1 of 0.11K.

A bias of ~0.14K in the mean between dual-view 3-channel SSTs and dual-view 2-channel SSTs has been confirmed for the years results, where the D3 SSTs are warmer than the D2. This confirms the behaviour reported in the validation report of December 2002. These biases were not removed during this work, and it is observed from comparisons that the D2 SSTs are closer to reality implying that the D3 SSTs are too warm. These differences indicate that actual day/night differences in SST from diurnal warming will be influenced by the biases in the two retrieval methods.

Results presented in Section 4.3 describe how the comparison of the September HadISST product using AVHRR with and without the in situ SST correction, and the same comparison using AATSR data confirm that AVHRR requires a greater correction in the east Atlantic region than AATSR. The initial AVHRR data is more than 0.3 K greater than the corrected AVHRR data through much of this region, while the initial AATSR is generally within ±0.1 K of the corrected AATSR here. This provides evidence that the aerosol correction in AATSR SST data gives it an advantage over AVHRR.

Future work should aim to provide a Meteo product SST which is unbiased between day and night, through empirical and theoretical studies. Firstly, the interalgorithm differences should be understood fully, and secondly a scientifically robust means of correcting them should be produced.

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